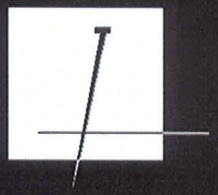
Tilt Fracture Mapping Analysis



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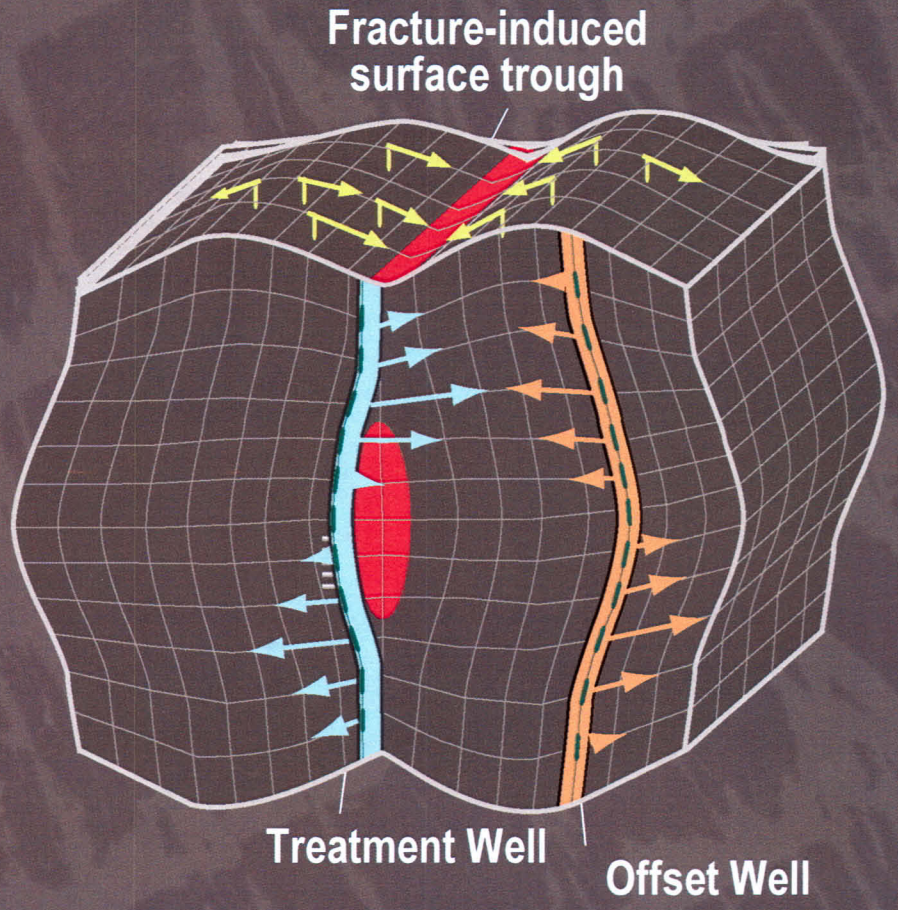
Real-time Engineering Solutions

Fracture Mapping Reservoir Monitoring Engineering Services Modeling Software

Principle of Tilt Fracture Mapping
Direct Fracture Diagnostic Technique

Hydraulic fracture induces a characteristic deformation pattern

Induced tilt reflects the geometry and orientation of created hydraulic fracture



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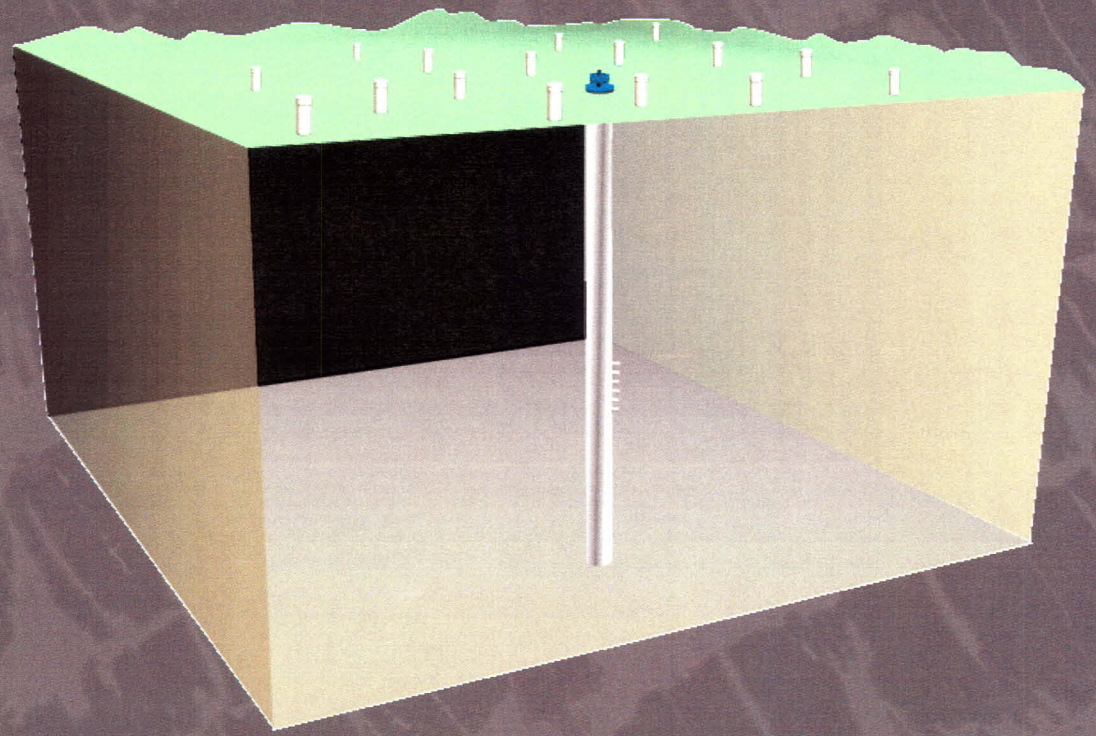
Well with Tiltmeter Sites Above



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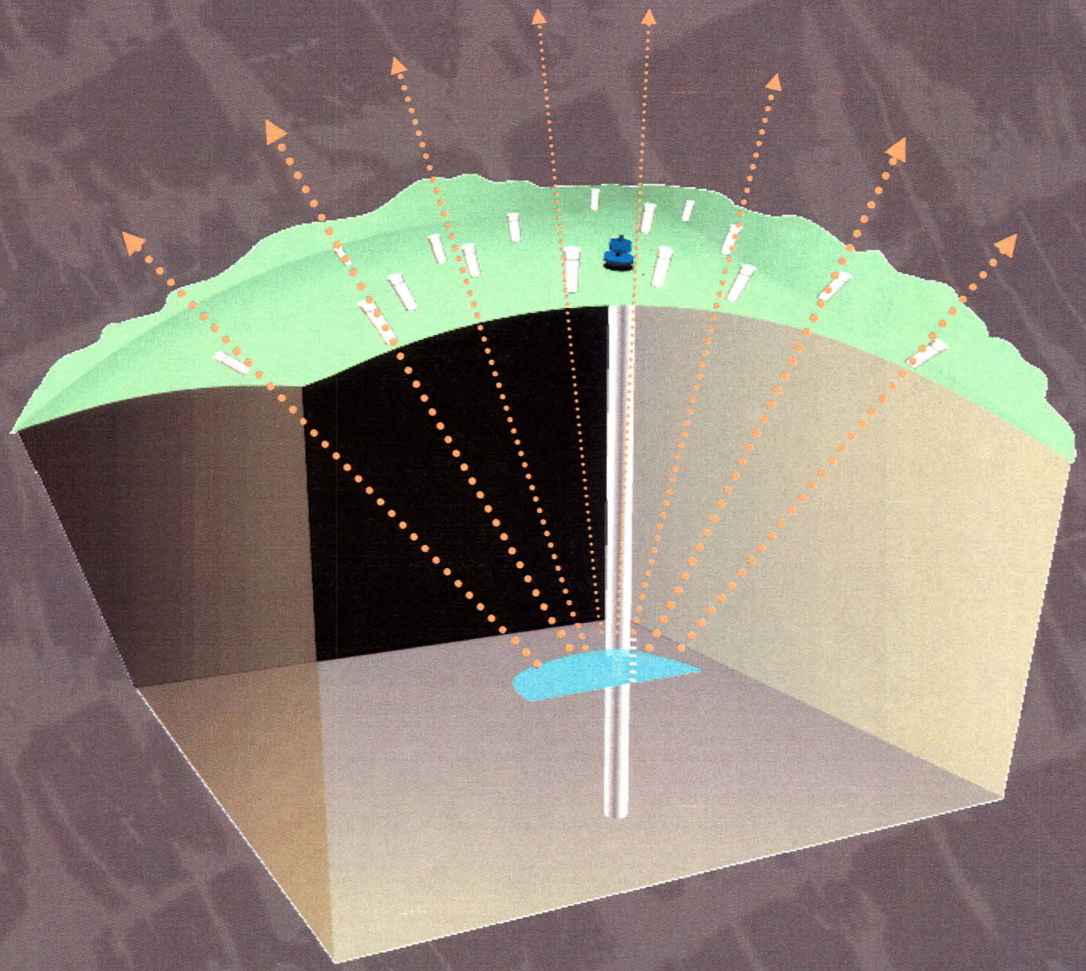
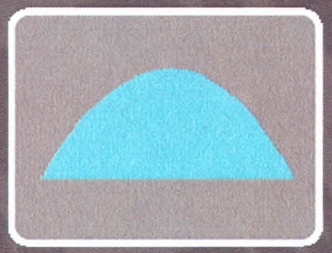
Horizontal Fracture





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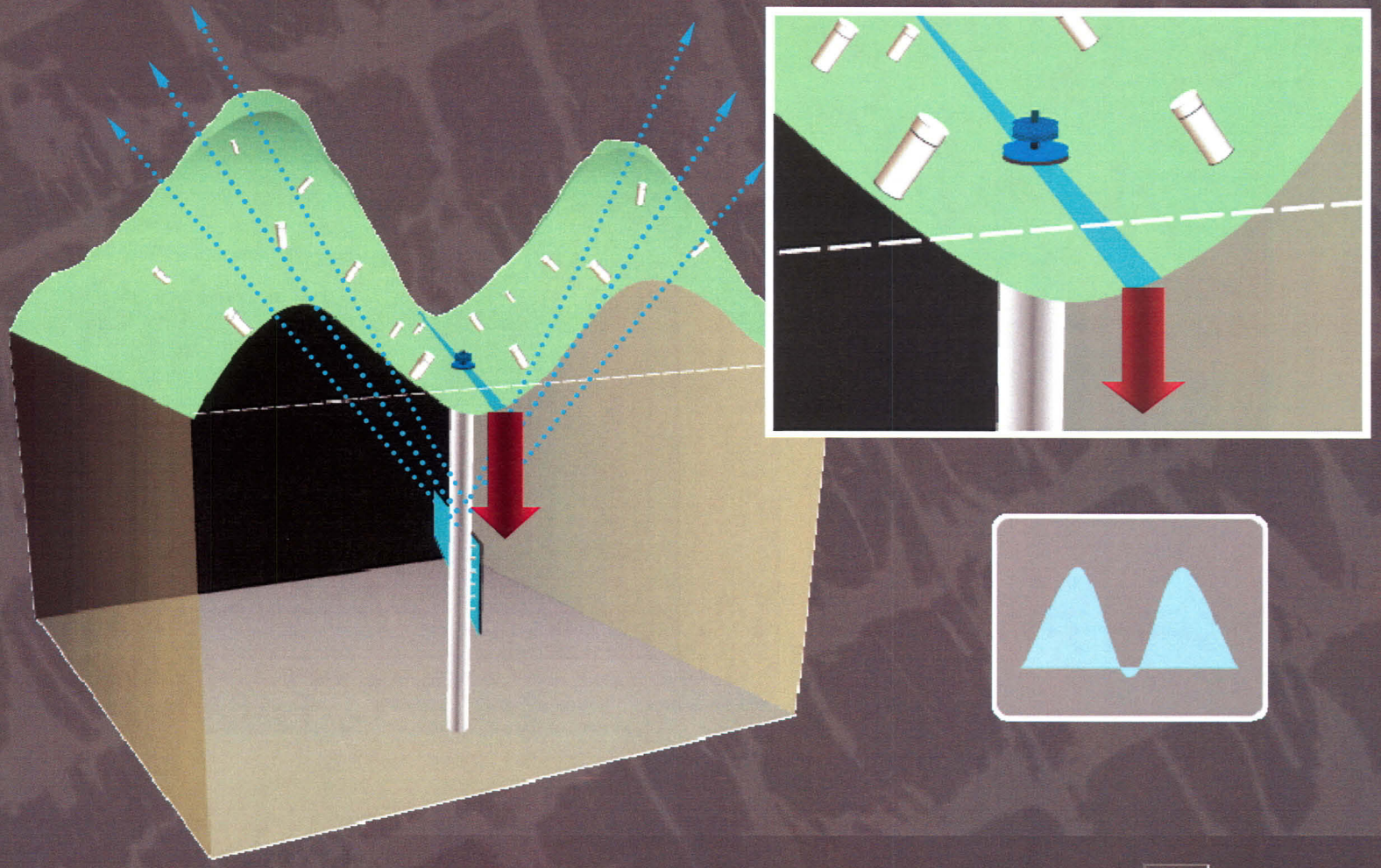
Vertical Fracture



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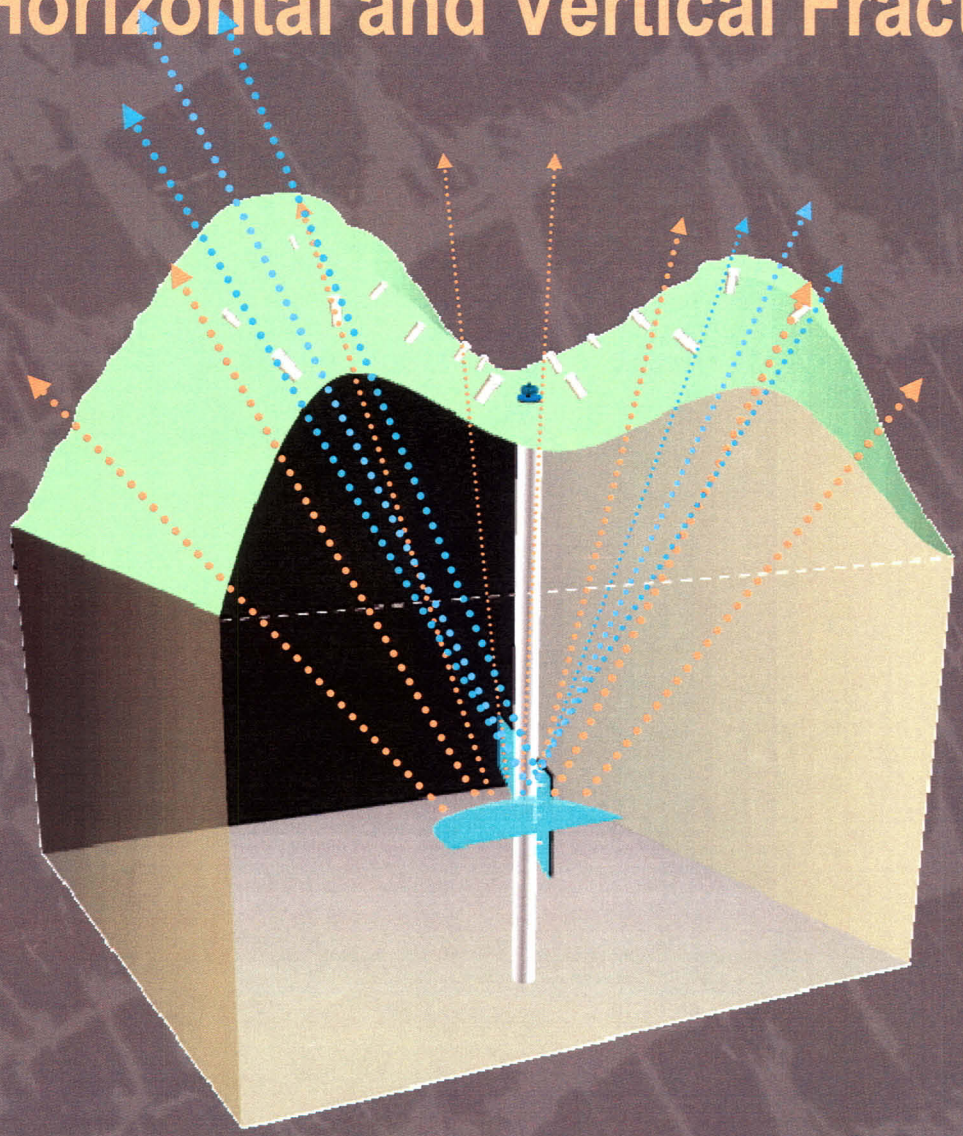
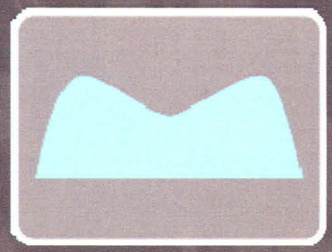
Dual Horizontal and Vertical Fractures





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Focus of Tilt Fracture Mapping

- Surface Tilt Fracture Mapping
  - Fracture Azimuth, Dip, and Volume
  - Approximate fracture center location (depth to center and lateral center shift)
  - Volume distribution along wellbore in horizontal wells
- Downhole Offset Tilt Mapping
  - Fracture height and half-length
  - Approximate width
- Treatment Well Tilt Mapping
  - Fracture height and width
  - Need to calculate fracture half-length using volume

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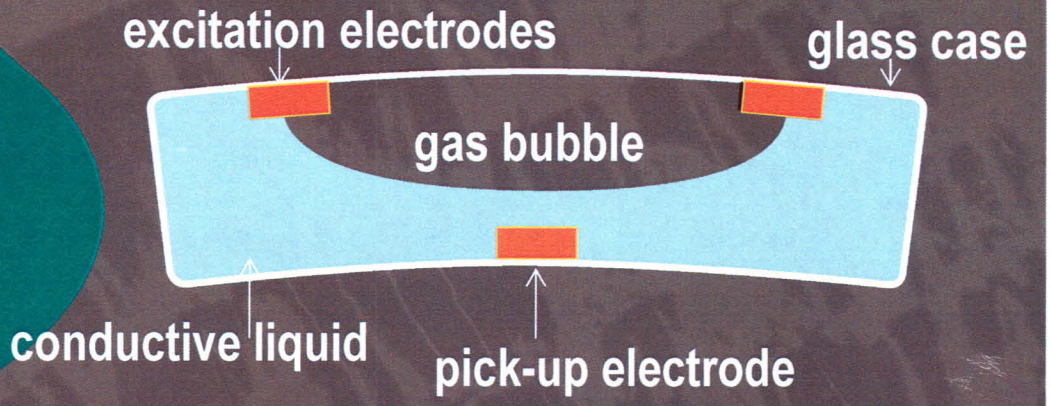
Principle of a Tiltmeter

A tiltmeter is a very sensitive carpenter's level

When the sensor tilts the resistance between the electrodes changes



Can measure tilt down to ~1 nanoradian (1 billionth of a radian; equivalent to lifting one end of a beam between New York and San Francisco by 1/4 inch)

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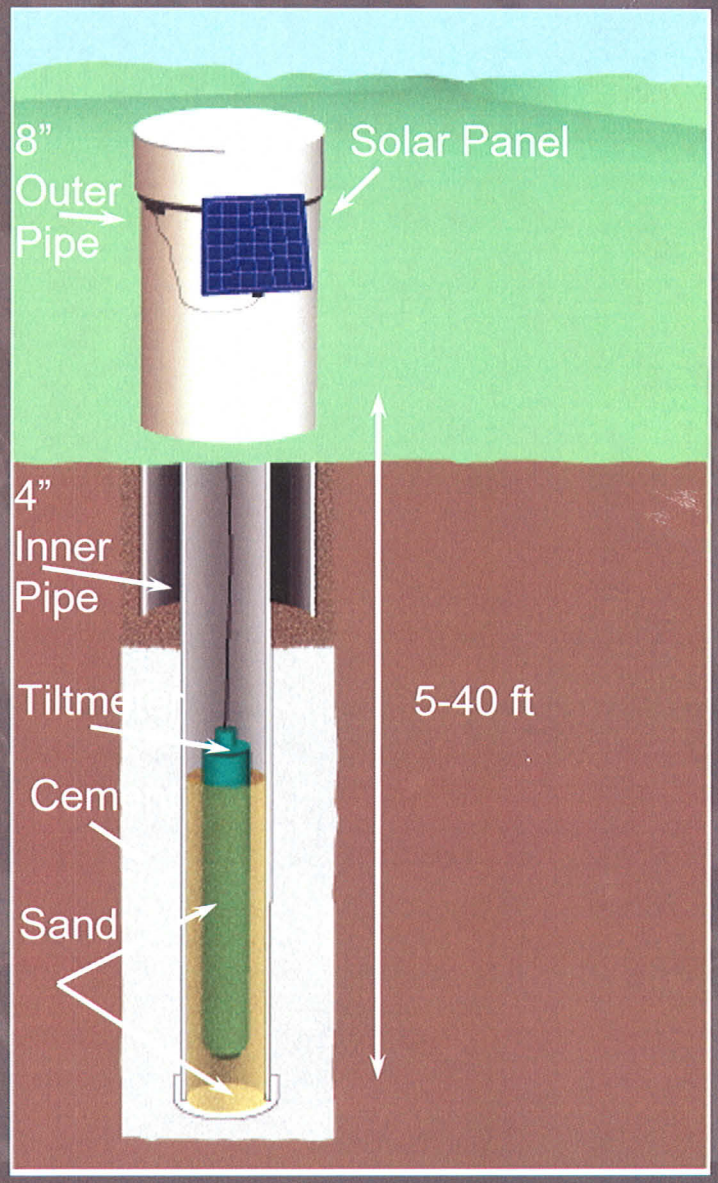
Surface Tiltmeter Site

- Installed 5 - 40 ft below the earth's surface in 4"-diameter PVC pipe
- Deeper boreholes to eliminate "noise" from surface
  - Cultural noise
  - Thermal induced earth surface motion
- Surface array with 16 or more tiltmeters placed in concentric circles around the point of injection (distance from well: 15%-75% of injection depth)
- Tiltmeter data stored in datalogger contained in tiltmeter
- Data collected periodically either manually or by radio



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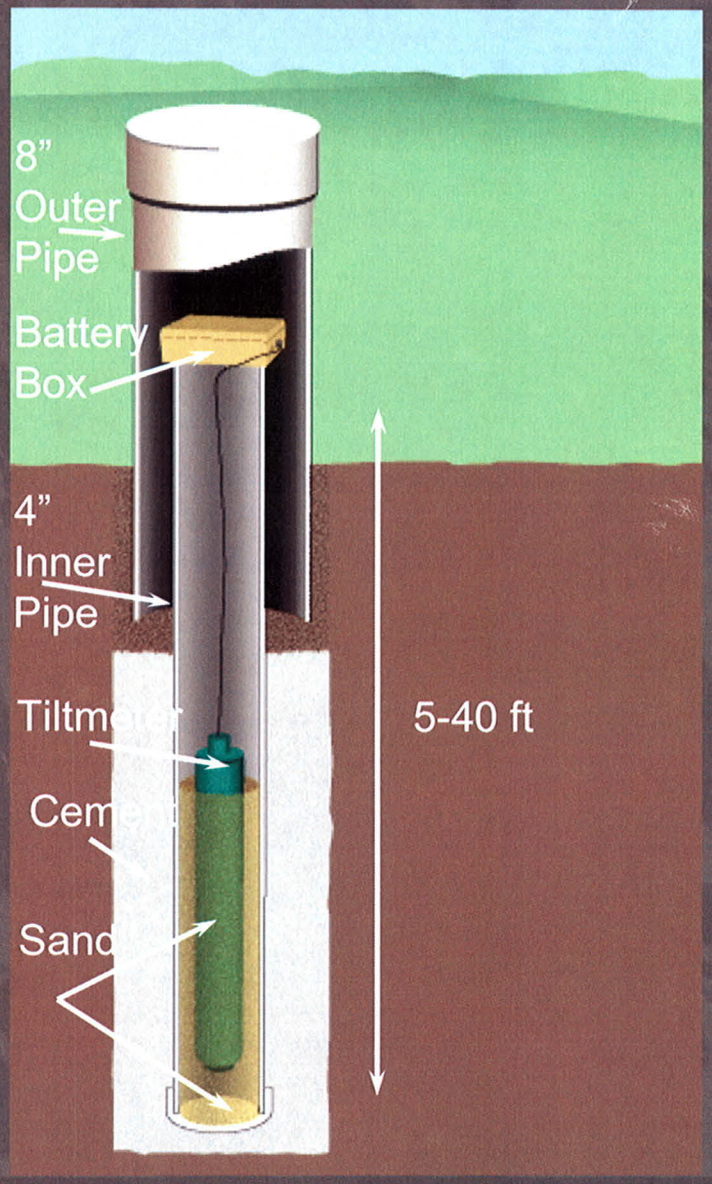
Surface Tiltmeter Site

- Hole is drilled 5-40 feet
- Inner 4 inch pipe is glued together and cap is glued on the end
- Inner Pipe is secured in hole and cement is filled around it up to 6 feet from surface
- A foot or two of dirt is kicked in on the cement
- The 8 inch outer pipe is placed on the dirt and then more dirt is filled around it



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Automated Data Collection

Radios transmit data continuously or on a set schedule

Collection computer assembles data and transmits it to Pinnacle

Data analyzed at Pinnacle and posted on secure internet site for client review

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What is needed to perform the Tilt analysis?

- Items needed from Clients:
  - For Surface Jobs
    - Well location, Trajectories and Completion for both treatment well and observation well
    - Treatment Info (Start/Stop Time and Slurry Volume in BBLS of Each Frac Stage)
    - Perforation Locations and Depth
    - Complete Treatment Info (Pressure and Rate vs Time) can be useful
    - Additional information (not critical but useful): Formation name, Rock type and some rock properties, reservoir type (i.e. crude oil -heavy, light -, gas, condensate, etc) and reservoir properties (permeability, porosity)
  - For Downhole Jobs
    - Everything needed for surface jobs
    - Observation Well Casing Weight/Size
    - Temperature Logs and Gamma Ray logs
    - Depth of Bridge Plug
    - Cross-overs (if any)
    - Flange Size

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